Electrochemical Oxygen Separation Using Solid Electrolyte Ion Transport Membranes

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Introduction

High purity oxygen is supplied commercially to many consumers as compressed gas in cylinders and as liquid in dewars or tanker trucks. For applications requiring oxygen purities of less than 93%, adsorption separation technology has provided some consumers with an economical option for oxygen produced on-site. Consumers demanding higher purity oxygen, however, currently have no alternative to distributed oxygen and its associated infrastructure requirements. A new technology employing ion transport membranes (ITM) has the potential to provide these consumers with economical, high purity oxygen via on-site generation[1].

In particular, the ITM solid electrolyte oxygen separation (SEOS) process enables the production of high purity oxygen at elevated pressure from a feed stream of ambient pressure air. ITM SEOS technology is based on the principle of oxygen ion migration through a dense ceramic electrolyte membrane under the influence of an externally applied electrical potential, as illustrated in Figure 1. The relationship between the equilibrium oxygen partial pressures on the anode and cathode side of the electrolyte is governed by the Nernst equation:

$$\Delta V = \frac{RT}{4F}\ln\left(\frac{p_{O_2,anode}}{p_{O_2,cathode}}\right)$$

Removal of the oxygen product from the anode side of the electrolyte membrane results in the continuous production of pure oxygen. The electrochemical reduction and oxidation reactions occur within porous electrode layers deposited on the solid electrolyte, specifically chosen for their ionic and electronic conductivity and catalytic activity.

Stack Materials

The core of SEOS technology is an electrochemical stack fabricated from high-temperature conductive ceramic materials. The solid electrolyte is based on cerium oxide, with dopants added to enhance both ion transport and membrane processability. To achieve sufficient oxygen ion conductivity through the electrolyte, the device must be operated at a temperature above approximately 600 °C. At these temperatures, doped cerium oxides exhibit a significant performance advantage over the zirconia-based materials commonly used in solid oxide fuel cells (SOFC). For example, the conductivity of Gd-doped ceria at 800 °C is about 0.1 $S \cdot cm^{-1}$, and is approximately one order of magnitude higher than that of YSZ[2]. Electrochemical test data have established cell performance over thousands of hours and have enabled optimization of electrolyte and electrode characteristics.

The principle of electrically driven ion migration provides the mechanistic basis for SEOS technology. However, a device comprising several cells, in series or in parallel, is required for commercial use. An efficient means for accomplishing this goal involves a flat plate multi-cell stack. Each cell, comprising a dense electrolyte coated with porous anode and cathode layers, is in contact with a dense interconnect made from an electronically conductive perovskite material. Each interconnect is featured to provide appropriate passages for the feed and product streams. The repeat units of the SEOS stack, connected electrically in series, also include biasing electrodes and offset glass-ceramic seals to maintain seal integrity under operating conditions. All materials must be carefully selected to meet criteria for thermal expansion match, chemical compatibility, and mechanical robustness, as well as ionic and electronic conductivity.

Balance of Device

The capacity for electrochemical gas compression is implicit in the Nernst equation. SEOS technology therefore enables separation and compression of high purity oxygen in a single step, without the use of an external compressor. The only moving part in an operating SEOS prototype unit is an air blower for the feed stream. In addition, a power supply and control systems are required. Particular challenges are presented by a thermal management system designed to balance the requirements of heating the feed air stream and cooling the product oxygen stream.

Successful leak-tight operation of multi-cell test stacks for thousands of hours has been demonstrated, in which oxygen has been consistently produced at high purity. Analytical techniques employing a high sensitivity discharge ionization detector have indicated a purity of greater than 99.99% for oxygen produced by a SEOS stack.

References

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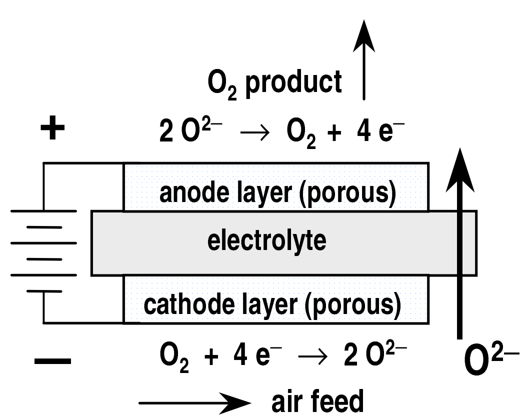

Figure 1: Schematic operation of a single electrochemical cell in an ITM SEOS device.